

Power Islands for Small Modular Reactors (SMR)

Ushering in the Next Era of Nuclear Energy

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Small Modular Reactors are emerging as a new power plant technology delivering reliable, emission-free power. With proven steam turbine and generator solutions, Siemens Energy is ready: fit-for-purpose, scalable, and robust. SMRs are a crucial step in the energy transition to reduce emissions. Nevertheless, this transformation will only succeed if strong partners collaborate to tackle this field together. This white paper outlines our scope of supply and how we are ready to partner with players from design to operation.

**Best regards,
Tobias Panse**

Senior Vice President, Steam Turbines and Generators Siemens Energy

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Executive Summary

After decades of limited growth, the global nuclear energy industry is experiencing a resurgence. Once considered a stagnant sector weighed down by regulatory hurdles, public skepticism, and high costs, nuclear power is now regaining prominence as the world grapples with the urgent need to decarbonize energy systems while maintaining reliable baseload power. A major driver of this renaissance has been the development of small modular reactors (SMRs), which are attracting attention from both governments and private industry for their ability to serve industrial sites, data centers, utilities, etc.

Siemens Energy is a global leader in power islands for conventional nuclear plants and has been a trusted technology partner to the industry for more than half a century. Today, over 60,000 Siemens Energy steam turbines are in operation worldwide, including 114 GW of installed power in nuclear applications. We are now applying our competency and experience in large-scale nuclear plants to SMR power islands. This paper provides a basic overview of the SMR concept and discusses how Siemens Energy is supporting projects with solutions for rotating equipment, instrumentation and control systems, electrical balance of plant (eBOP), and grid integration.

Introduction

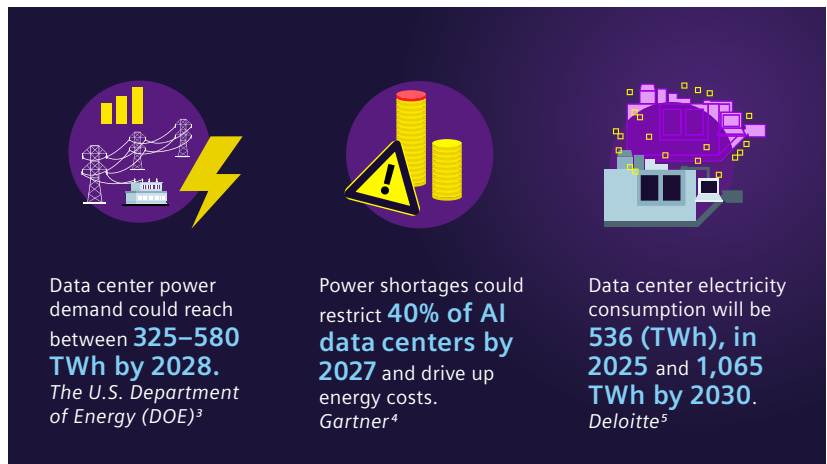
Global energy consumption is projected to grow steadily over the next three decades. This results in the “energy trilemma”: A successful energy transition requires balancing affordability, reliability, and sustainability. Meeting this demand sustainably and cost-effectively will be a monumental undertaking. Global CO₂ emissions were over 41 billion tons in 2024 (a record high).¹ This comes at a time when energy security and affordability are a growing concern for a large portion of the developing world. Today, an estimated 750 million people still lack access to a reliable source of electricity.

Solving the “energy trilemma” will require contributions from a wide range of sources. Accelerating the build out of renewables, including solar and wind, will be crucial to meeting climate targets. However, conventional power sources, such as natural gas, nuclear, and hydro, along with energy storage will be needed to address intermittency issues and ensure security of supply.

The world is currently experiencing a renaissance in nuclear energy. According to the International Energy Agency (IEA), interest is at its highest level since the oil crisis in the 1970s and support for expanding the use of nuclear power is now in place in 40+ countries. Much of this renewed interest is in small modular reactors (SMRs), which are gaining traction due to their promise of lower costs, higher security level, and shorter development cycle relative to conventional nuclear power plants (NPPs).

Although the future is highly uncertain, initial baseline forecasts from the IEA are for SMR capacity to reach anywhere from 40 GW to 120 GW by 2050. The upper end of this range reflects a highly favorable regulatory environment, with tailored policy support from governments. In such a scenario, the predicted number of SMRs in operation worldwide reaches ~1,000.²

Much of the market growth for SMRs in the coming years is expected to originate from the data center industry especially in the US-market. This is particularly the case in North America, where the rise of artificial intelligence (AI) has led to a substantial increase in the demand for electricity to power graphics processing units (GPUs). Large, hyperscale data centers require 100 MW or more of continuous power. The high availability requirements of these facilities (often 99.9+%), coupled with a prioritization on reducing carbon emissions, lends well to SMRs.



Interest in SMRs is also growing outside of data centers. Some applications where they are being considered include industrial facilities (e.g., for combined heat and power, ammonia production, etc.), desalination plants, and utility-scale power generation for grid support.

Siemens Energy is not involved in developing nuclear fission reactors. However, our decades of experience in conventional nuclear power islands makes us an ideal supplier for SMRs. With a comprehensive portfolio that spans steam turbines, generators, operational instrumentation and control systems, as well as the electrical balance of plant (eBOP) and grid integration, we are uniquely positioned to support SMR plant development and help drive projects to final investment decision (FID).

- 1 World Meteorological Organization (WMO)
- 2 International Energy Agency (IEA)
- 3 World Meteorological Organization (WMO)
- 4 International Energy Agency (IEA)
- 5 U.S. Department of Energy (DOE)

SMR Concept Overview

SMRs are compact nuclear power plants, often referred to as “mini” NPPs. Their components can be prefabricated and assembled in a factory, then transported to the site ready for use. This significantly reduces the time, complexity, and cost associated with bringing nuclear reactors online.

Most of the SMR concepts work similarly to traditional nuclear reactors but on a smaller scale. The core contains nuclear fuel, typically uranium, which releases heat through nuclear fission. This heat converts water into steam, which drives a turbine connected to a generator, producing clean electricity. The reactor technology is essentially the same as that of a conventional nuclear power plant. Typical sizes for SMRs today range from 50 to 300 MW.

One of the main advantages of SMRs is that they require significantly less space than conventional NPPs and also have a notably smaller footprint. The exact footprint varies depending on the design and power output, but generally, an SMR will occupy only a fraction of the space required by a conventional reactor (about 0.01 square kilometers vs. 1–2 square kilometers for a conventional nuclear plant). Like a traditional NPP, electricity production can be flexibly adjusted to meet demand. Several proposed SMR GenIV



Understanding reactor technology

Nuclear reactors are categorized into different generations based on their design, technology, and safety features. Generation III+ reactors improve upon Generation III reactors, which have been in operation since the 1990s, by offering increased safety, efficiency, and operational lifetimes. These reactors have passive systems that function without human intervention or external power in emergencies. Generation IV reactors utilize novel coolants, fuels, and configurations, and often feature closed fuel cycles. Examples include Sodium-cooled Fast Reactor (SFR), Molten Salt Reactor (MSR), High-Temperature Gas-Cooled Reactor (HTGR). Today, roughly 80 SMR designs are under development, including several designs that are already in operation.

reactor designs are capable of operating at higher temperatures than conventional nuclear power plants, making them especially advantageous for zero-emissions heat applications such as process heating, district heating, and other industrial thermal uses.

6 Nuclear Energy Agency (NEA)

Currently, there are three SMRs in operation worldwide: one in China, one in Russia, and a test reactor in Japan. Additional SMRs are under construction in Russia, China and Argentina. North America and Europe are home to most SMR plant designers. Around one-third of all SMR technology providers are headquartered in the U.S.⁶

Benefits of SMR



Clean Energy

Nuclear Power generates stable, reliable, and dispatchable electricity while having **near-zero CO₂ and NO_x emissions**



Availability

Nuclear Power operate at **much higher capacity and availability factor** than renewable energy or fossil fuels.



Modularity

Modular small components and factory fabrication are intended to **reduce construction capital cost and duration** as compared to conventional nuclear.



Policies / Acceptance

Strong political and institutional support are attracting **large private investment** and increasing the **public acceptance** of SMRs.



Safety

Improved safety measures with **high level of passive or inherent safety**.



More than Electricity

Nuclear power can be coupled with other renewable sources to produce higher efficiencies while **increasing the grid security and stability**. *In addition* it can provide heat to **industrial applications, desalination, energy storage, etc.**

Siemens Energy's Solutions for SMR Plants

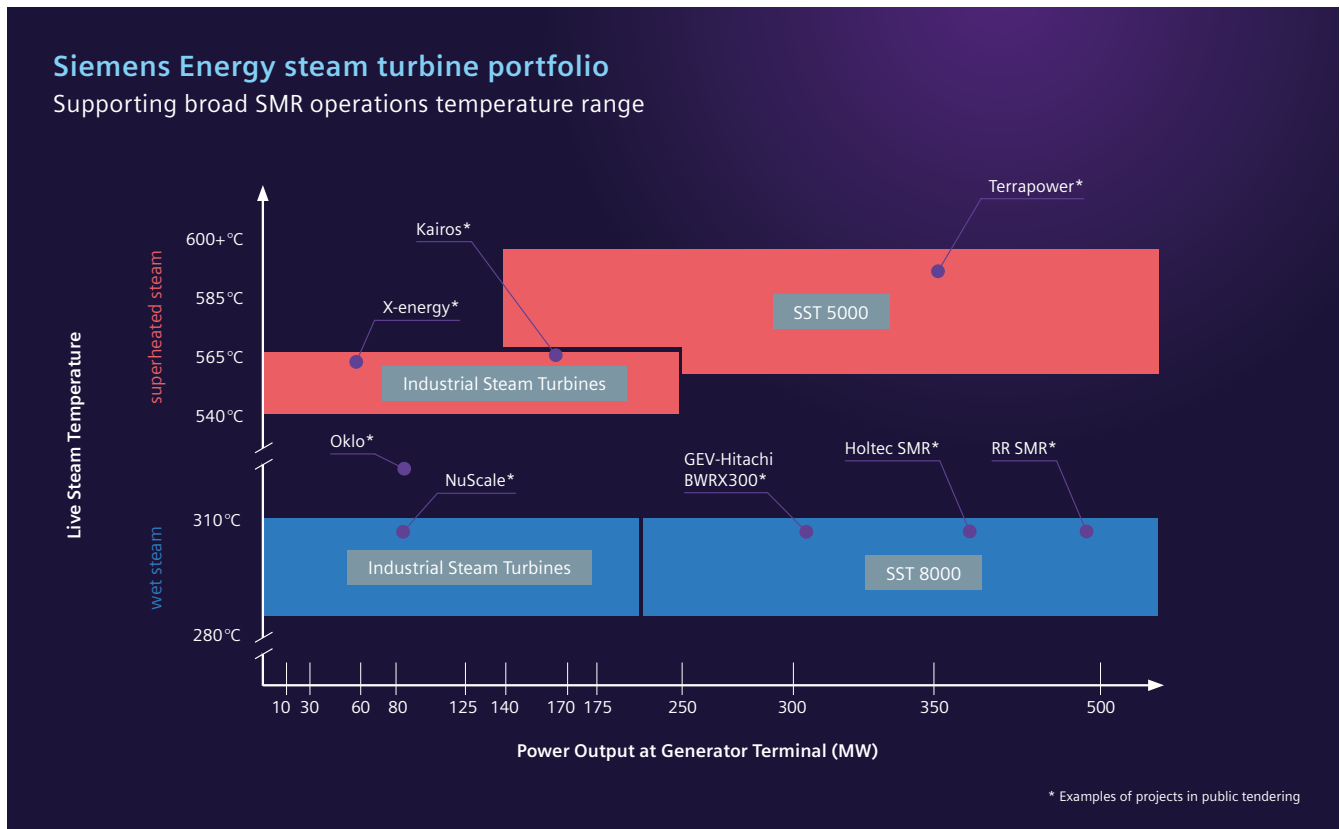
Siemens Energy has more than five decades of experience providing solutions to the nuclear power industry and is uniquely capable of supporting SMR projects. Our main scope focuses on the conventional island and covers the following critical systems:

- Steam turbine set, including generators and auxiliary systems
- Water-steam cycle
- Instrumentation & Controls (I&C) and Distributed Control System (DCS)
- Electrical infrastructure and balance of plant (eBoP)
- Back-up power equipment

Steam Turbine Generator Sets

Siemens Energy has a broad range of steam turbine generator (STG) trains to accommodate nuclear plants of any size – including SMRs with power outputs ranging from 2 MW to 300 MW. Backed by the extensive nuclear heritage of Siemens KWU, Westinghouse, and Parsons, our rich legacy spans more than 50 years and enables us to provide tailor-made solutions that cater to the distinctive needs of SMR plants. All our STG trains are designed for easy constructability, fast start-up, and economical operation. Today, more than 60,000 Siemens Energy steam turbines are in operation worldwide, including 114 GW of installed power in nuclear applications.





The **SST-600** (up to 200 MW)- **SST-800** (up to 250 MW) as well as the **SST-5000** and **SST-8000** (up to 500 MW) represent ideal solutions for larger SMR applications and offer high power output in a single casing. Both steam turbines can be directly coupled to generators and are available in single lift configurations, which provides several advantages when it comes to installation and commissioning.

Integration of the steam turbine, gearbox, generator, and auxiliary systems on single base frame at Siemens Energy’s manufacturing factory facilitates “plug and play” installation and commissioning. This reduces construction requirements and associated

schedule interdependencies – with the majority of onsite work confined to site preparation and civil works. Safety is also improved, as the total number of workers onsite is greatly reduced.

Through our Dresser-Rand steam turbine portfolio, Siemens Energy can also support small or mobile SMRs (<5 MW) that utilize the Brayton Cycle. Dresser-Rand steam turbines include:

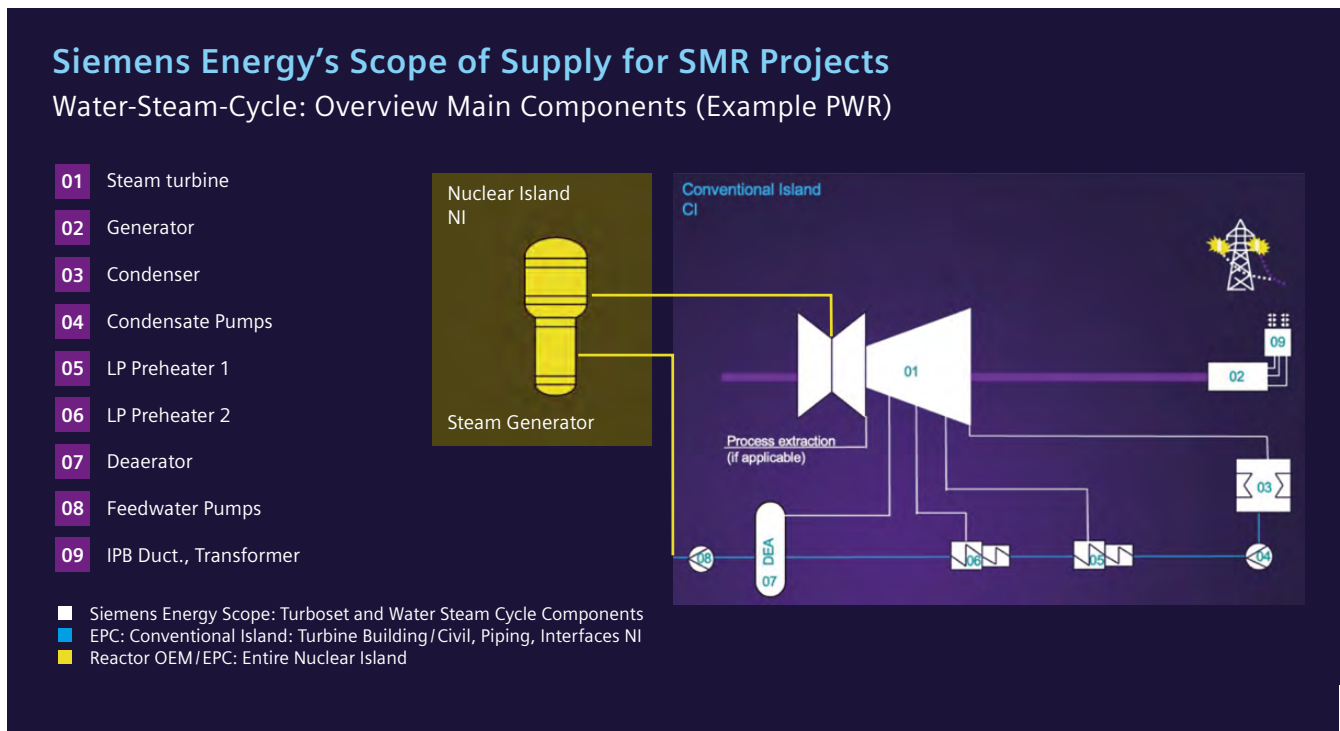
- Standard single stage turbines as mechanical drives for feed water pumps and as service replacement drives for feedwater pump drives for large nuclear plants

Water-Steam-Cycle

Siemens Energy’s scope of supply for SMR plants covers the entire water-steam cycle, including condensers, moisture separator reheaters (MSR), pre-heaters and vessels, pumps, drives, etc. We draw on our extensive history providing power islands for conventional nuclear and combined cycle power plants to optimize water-steam cycles, enabling maximum efficiency and power output.

cycles, feedwater heating, and other techniques can significantly improve plant efficiency, reducing the cost per megawatt-hour of electricity generated.

Available plot space can be another constraint in SMR designs. The steam cycle must be tightly integrated with other plant systems without sacrificing performance or safety. This demands innovative design approaches, including the use of compact heat exchangers, direct cycle integration, and carefully planned piping networks.



The water-steam cycle involves heating water using the thermal energy generated by the SMR. The resulting steam drives the STG. The steam is then condensed back into water and recirculated. In traditional large-scale nuclear plants, water-steam cycles are well-established. However, SMRs, with their unique reactor configurations, modular designs, and deployment environments (including off-grid), introduce new challenges and opportunities when it comes to system design.

The thermodynamic cycle also influences plant safety. For instance, the ability to rapidly reject heat during transients or emergencies is closely linked to condenser performance and coolant flow characteristics. An optimized water-steam cycle ensures stable operation under varying load conditions, thereby minimizing the risk of pressure imbalances or thermal stresses, and supporting passive safety features that are central to SMR designs.

Water steam cycle for Gen IV reactors. Further conventional island equipment including MSR can be provided for large conventional and GenII+SMRs.

SMRs inherently have lower thermal output compared to traditional reactors. This puts a high value on extracting the maximum possible electrical energy from the available thermal energy. Thermodynamic optimizations such as superheating, reheat



Long-term Service Programs (LTPs)

Siemens Energy offers a range of service programs for nuclear steam turbines and generators which promote optimal performance. We can tailor the contract scope to meet individual requirements of the SMR plant, helping operators maximize power island performance, reduce downtime, and mitigate risks. Our flexible portfolio ranges from individual operations and maintenance (O&M) services to all-inclusive LTPs with performance guarantees. Services include:

- Routine maintenance and inspections
- Onsite repairs and testing
- Modernizations and upgrades
- Spare parts supply and management

Remote Diagnostic Services (RDS) can be added as an optional service to support preventive maintenance through early detection of potential equipment issues. RDS facilitates a collaborative, data-sharing model between the power island OEM and plant operator. The OEM receives a continuous stream of real-time data from the unit(s). With full transparency, dedicated engineers can then act as a natural extension of the customer team by providing advanced troubleshooting and 24/7 remote support, along with recommendations for corrective maintenance, all without having to be physically onsite.

Instrumentation & Control (I&C) Systems

SMR power islands involve the coordination of multiple dynamic processes, such as steam generation, pressure regulation, turbine speed control, generator synchronization, and load dispatch. I&C systems ensure these processes are continuously and precisely controlled through automated control loops that respond in real-time to changing conditions.

Siemens Energy is a global leader in I&C systems for power generation applications, including NPPs. Today, we are the #1 supplier for conventional and nuclear power plant automation in Europe. For SMR, we envisage synergies between both areas. Our I&C solutions have a proven history of ensuring safe, reliable, and efficient performance in steam turbine-based power islands. Today, nearly one-quarter of all nuclear power plants worldwide and 100% of large-scale nuclear plants in Europe utilize Siemens Energy I&C technology. In total, we serve a fleet of ~4,500 power generation installations around the globe.

Nuclear Operational I&C

Siemens Energy Nuclear I&C platforms cover the complete NPP Operation



Level 2

Human Machine Interface
SPPA-T2000 OM690
Omnivise T3000 HMI



Level 1

Automation
SPPA-T2000 AS620B
Omnivise T3000 Automation



Level 0

Instrumentation Equipment

Electrical Infrastructure and Balance of Plant (eBOP)

Siemens Energy provides eBOP equipment to manage the power generation, transmission, and distribution within the SMR plant. These components are used to control, regulate, and monitor the generated electricity and include high-, medium, and low-voltage transformers, switchgears, power quality solutions, etc. We combine our own product portfolio with third-party technologies to design a customized solution for the SMR plant, taking into account economic factors, as well as important metrics such as availability, safety, and efficiency.

One significant advantage Siemens Energy possesses over many other power equipment OEMs is the ability to supply the equipment for the SMR plant’s electrical distribution and transmission system. This includes trans-

formers for all outputs and voltages, cooling types, and operation modes, as well as technology for ensuring grid compliance if the plant will be connected to the external grid. Designing the power island in conjunction with the electrical system supports total optimization of the facility and minimizes the risk of schedule delays caused by vendor interface issues.

Back-up Power Equipment

Siemens Energy provides back-up power solutions for SMR-based plants, including aeroderivative and industrial gas turbines and battery energy storage solutions (BESS).

Gas turbines, either as temporary or permanent fixtures, can provide sustained power for longer periods of time during planned or unplanned outages of the plant.

SC, Prot. Studies	DC and emergency systems	Security systems
Transformers and reactors	Inverters and rectifiers	Lighting and small power systems
Metering	Control and protection system	BESS systems
PF compensation systems	Excitation systems	Containerized solutions
MV and LV systems	Frequency converters and soft starters	Auxiliary support systems
IPB and AIS busbars	Communication systems	Power quality management

Conclusion: Embracing Strategic Partnerships

Today, nuclear power accounts for approximately 10% of electricity generation globally and is the world's second largest source of low-emissions electricity behind hydropower. Cost-competitive SMRs, supported by favorable regulatory policies and incentives, have the potential to increase nuclear power's share in the energy system and accelerate decarbonization of data centers, industry, and the broader electrical grid.

While momentum behind SMRs is building, projects in the early development stages still face challenges. The high initial investment needed for deploying these technologies, coupled with a very limited operational history, makes it difficult for stakeholders to justify investments compared to more established clean energy sources. The complex regulatory landscape for nuclear technology has also created apprehension among developers and financiers, particularly with respect to potential delays and cost overruns.

Despite these hurdles, the burgeoning demand for clean and non-intermittent electricity creates a strong rationale for deploying SMRs. However, like any nascent technology or concept, making projects bankable requires alignment among stakeholders and close collaboration early on between key providers (particularly the SMR licensor and power island OEM) to mitigate risk and reduce plant total cost of ownership. Governments also have an important role to play in reducing risk and encouraging investment in these projects through pragmatic policy.

Siemens Energy is a technology leader in conventional islands for NPPs. Our ability to handle a substantial portion of an SMR plant's scope (from the steam turbine generator sets and water-steam cycle, to electrical distribution systems and I&C) benefits projects by reducing interface risk and facilitating seamless execution across the development cycle. As interest in SMR technology grows, we are committed to supporting the industry by using our experience and expertise to drive projects to FID.

To learn more about Siemens Energy's power island solutions for SMRs, contact

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